Energy, Technological Change, and Air Emissions: U.S. EPA MARKAL Modeling

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EPA Energy System Analysis

- Origins in EPA's *Global Change Research Program*
- How might global climate change affect regional weather and (in turn) atmospheric pollution?
- Drivers of atmospheric pollution:
  - Chemical reaction and transport
  - Biogenic emissions
  - Anthropogenic emissions
- Technological change is fundamental to the latter
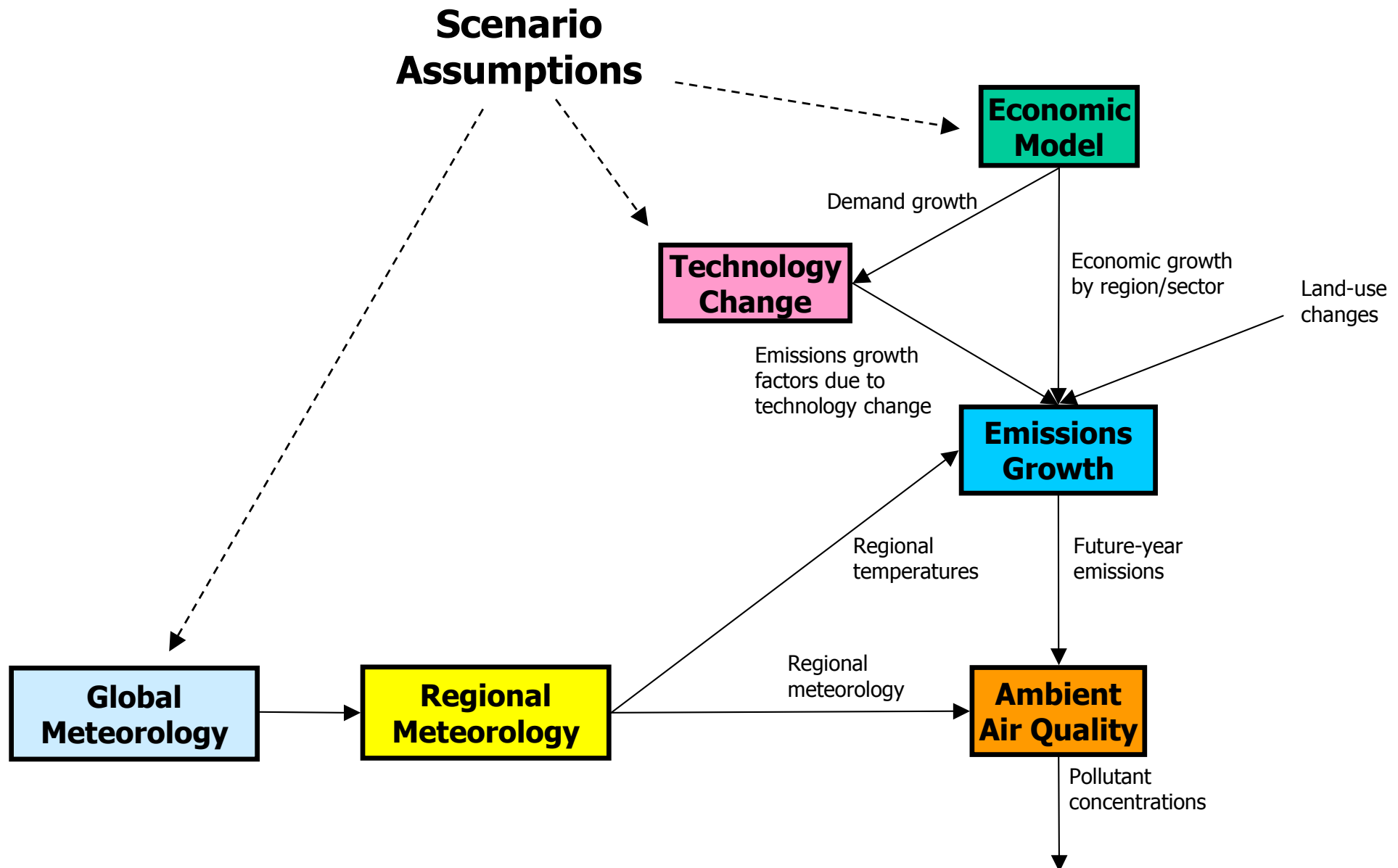
EPA Modeling Goals

- Develop and assess scenarios of energy technology evolution in emissions-intensive sectors of the U.S. economy (transportation and electricity) and calculate associated emissions trajectories

- Scenario analysis – *NOT* prediction

- Focus on 2000 to 2050 timeframe

- Take into account driving forces:
  - Technological change
  - Energy supply, demand, and price dynamics
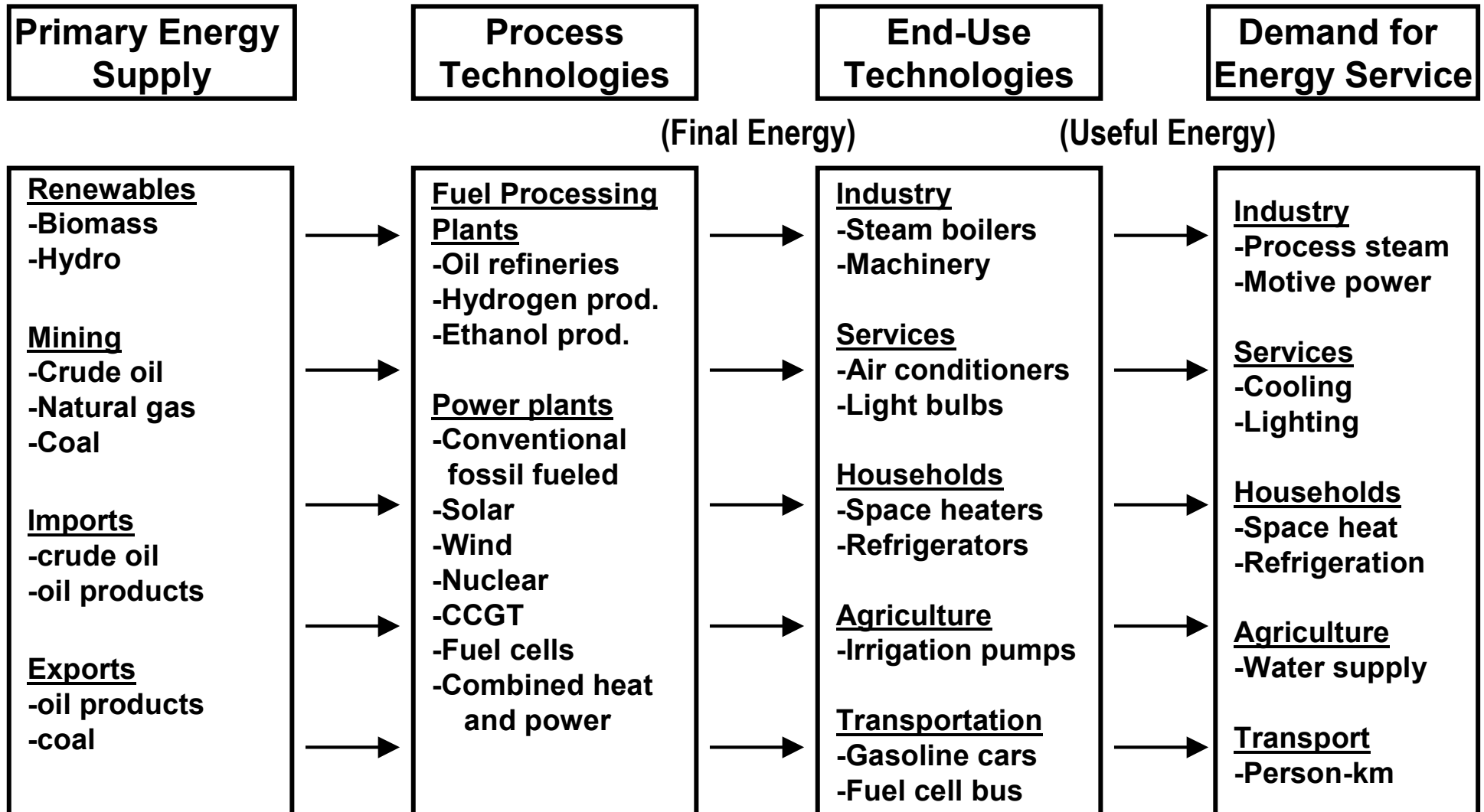 - Environmental, energy, and land use policies

The MARKAL Energy Systems Model

- Finds a least cost set of technologies to satisfy end-use energy service demands and user-specified constraints (linear optimization)

- Calculates resulting environmental emissions

- Quantifies the system-wide effects of changes in resource supply, technology availability, and energy and environmental policies

- Provides a transparent framework for exploring and evaluating alternative futures
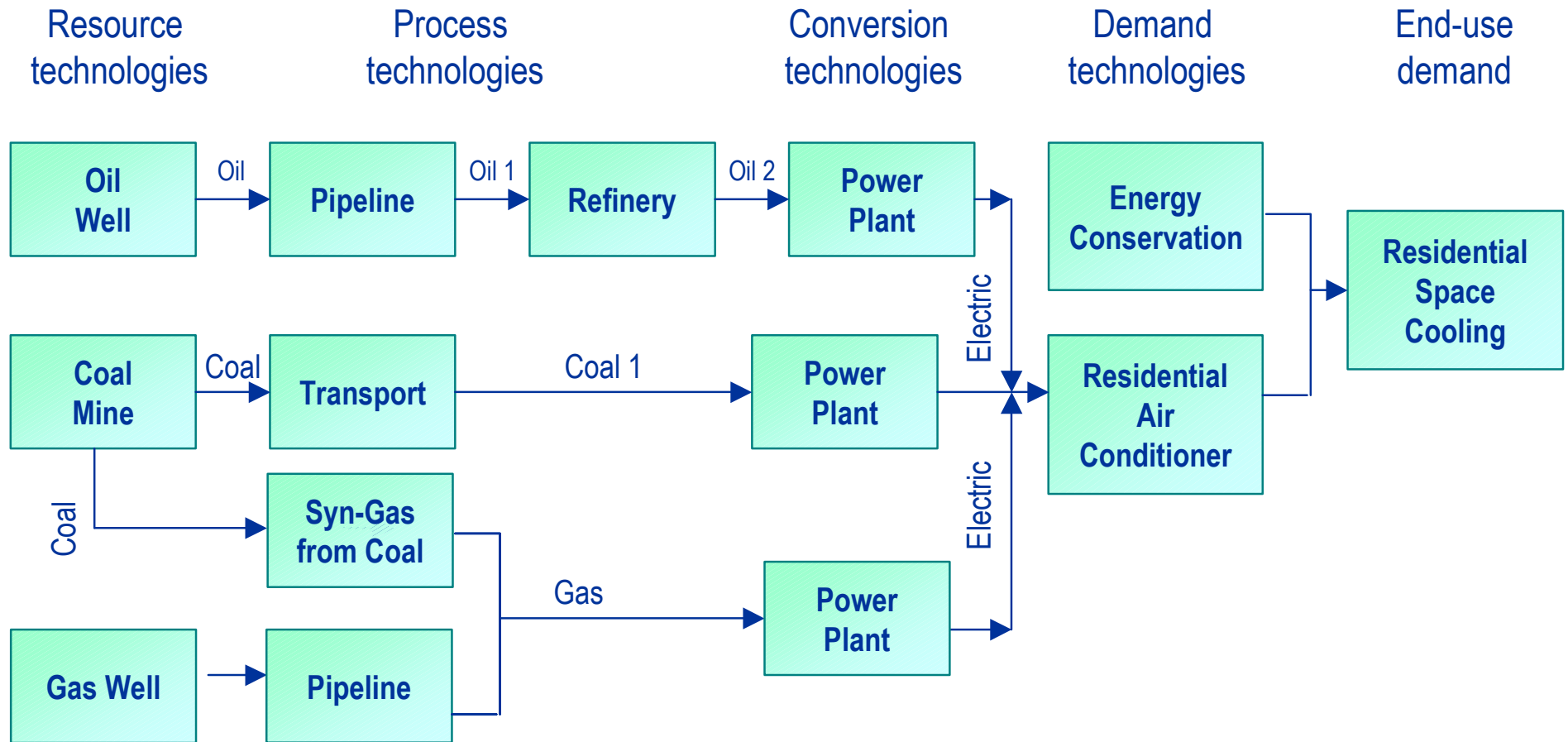
How MARKAL Works

- Represents all energy producing, transforming, and consuming processes as an interconnected network (Reference Energy System)

- Selects technologies to meet end-use service demands based on life-cycle costs of competing alternatives

- Minimizes aggregate system costs subject to specified constraints

MARKAL's Energy System Representation

Primary Energy Supply	Process Technologies	End-Use Technologies	Demand for Energy Service

(Final Energy)   (Useful Energy)

Primary Energy Supply

Renewables
-Biomass
-Hydro

Mining
-Crude oil
-Natural gas
-Coal

Imports
-crude oil
-oil products

Exports
-oil products
-coal

Process Technologies

Fuel Processing Plants
-Oil refineries
-Hydrogen prod.
-Ethanol prod.

Power plants
-Conventional
 fossil fueled
-Solar
-Wind
-Nuclear
-CCGT
-Fuel cells
-Combined heat
 and power

End-Use Technologies

Industry
-Steam boilers
-Machinery

Services
-Air conditioners
-Light bulbs

Households
-Space heaters
-Refrigerators

Agriculture
-Irrigation pumps

Transportation
-Gasoline cars
-Fuel cell bus

Demand for Energy Service

Industry
-Process steam
-Motive power

Services
-Cooling
-Lighting

Households
-Space heat
-Refrigeration

Agriculture
-Water supply

Transport
-Person-km

Simplified Reference Energy System

Resource technologies	Process technologies	Conversion technologies	Demand technologies	End-use demand

Oil Well → *Oil* → Pipeline → *Oil 1* → Refinery → *Oil 2* → Power Plant → *Electric* →

Coal Mine → *Coal* → Transport → *Coal 1* → Power Plant → *Electric* →

Coal Mine → *Coal* → Syn-Gas from Coal

Syn-Gas from Coal / Gas Well → Pipeline → *Gas* → Power Plant → *Electric* →

Energy Conservation → Residential Space Cooling

Residential Air Conditioner → Residential Space Cooling

Each box is a MARKAL technology

Each arrow is a MARKAL energy carrier

MARKAL Data Requirements

- Useful energy end-use service demands
- Available resource supplies and costs
- Technology characteristics
  - Existing capacity
  - Costs: investment, fixed, variable, fuel
  - Performance: fuels in and out, efficiency, emission rates, availability, lifetime
- Emissions constraints, taxes

EPA National MARKAL Database

Sector	Key Sources	Technologies
Transportation	DOE OTT, NEMS	15 personal vehicle technologies in 5 size classes; 40 other passenger and freight technologies
Electricity	NEMS, IPM	45 generating technologies
Commercial	NEMS	300 heating, cooling, ventilation, lighting, and refrigeration technologies
Residential	NEMS	135 heating, cooling, lighting, and refrigeration technologies
Industrial	SAGE	Framework covering 6 industries, 6 energy services
Coal supply	NEMS	25 types by region, sulfur content, and mine type; 8-step supply curves
Oil and gas supply	NEMS, USGS	5 grades of imported oil; domestic and imported natural gas; 3-step supply curves.

Current Technology Focus

- Electricity generation:
  - Advanced coal and natural gas plants
  - Renewables
  - Advanced nuclear plants
  - Carbon capture and sequestration
- Transportation:
  - Conventional and advanced gasoline and diesel ICEs
  - Gasoline and diesel hybrids
  - Hydrogen (and other) fuel cells
  - Biofuels
- Hydrogen Infrastructure

Ongoing and Future Work

- Improve representation of:
  - Renewables
  - Resource constraints
- Incorporate endogenous learning
- Examine the range of possible outcomes given a set of assumptions (using Modeling to Generate Alternatives)
- Conduct full sensitivity and uncertainty analyses
- REGIONALIZATION

Regional MARKAL: Motivation Behind NE Pilot Effort

- Decisions about technology and impacts from technology choice occur at regional and local scales

- Policy actions relevant to climate and air quality are being taken at regional and local scales
  - e.g., Criteria pollutant mitigation, technology portfolio standards, systems benefits charges, climate considerations

- States and local entities need tools to assess energy-technology-environment policies

New England MARKAL Project

- Northeast States for Coordinated Air Use Management (NESCAUM) is developing, hosting, and running the model

- Six states, each modeled as its own region (add NY, NJ, others?)

- EPA has sponsored development – not analysis
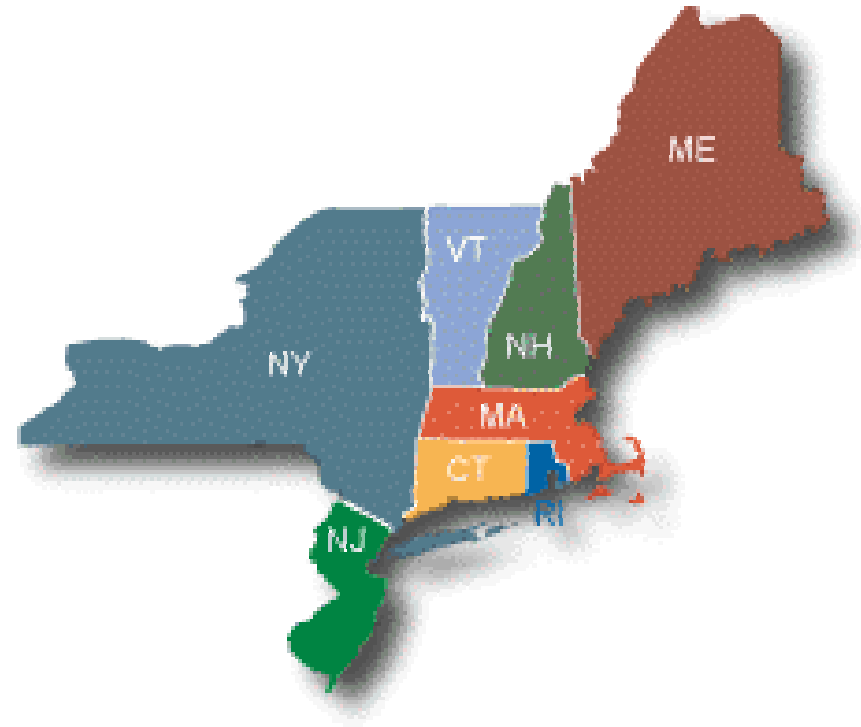
Outcomes: The New England Project Will . . .

- Determine what data are readily available at state and regional levels and what gaps must be filled

- Prepare structures for handling regional model data

- Test the model development and utilization process

- Provide a working example of the value a regional model can offer

Regionalization of EPA's National MARKAL Model: Motives

- Improve representation of:
  - Resource supply
  - Demand drivers (demographic, economic, climatic)
  - Existing technologies and fuel splits
  - Technology costs and availability
- Air Quality Assessment: Need geographic apportionment of emission growth factors
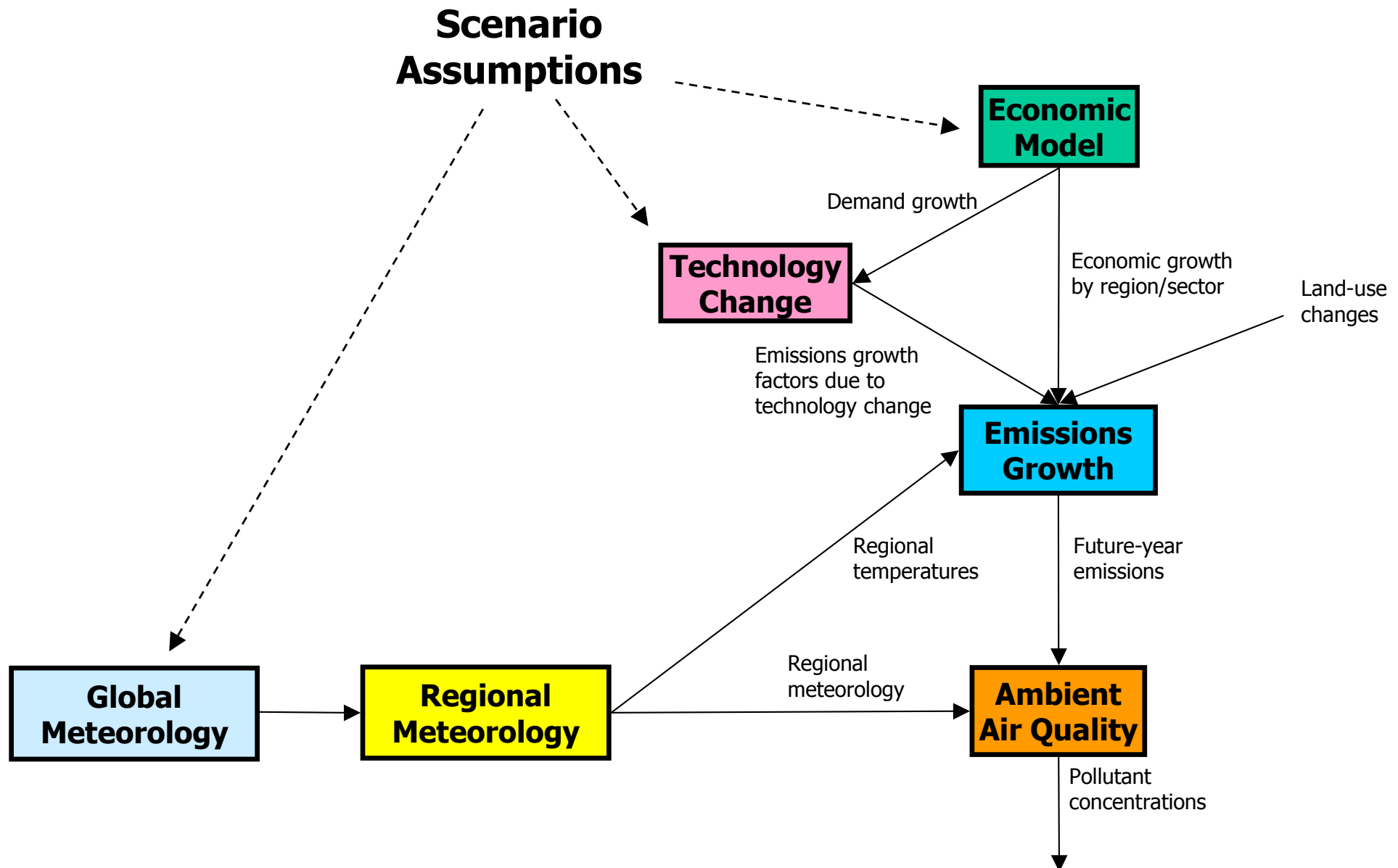
Model Disaggregation

- Disaggregate input or output?

- Issues:
  - Computational demand (trading becomes significant)
  - Data availability and consistency across regions

- Possible approaches to model regionalization:
  - Individual states
  - 31 supply regions (e.g., NEMS), 9 demand regions (Census)
  - Start small: incorporate detailed regions of interest (e.g., New England, Ohio?), representing remainder of nation as a single supply/demand region

Uses for a Disaggregated National Model

- Assess regional differences in technology suitability (wind, solar, biomass, CO_2 sequestration, distributed generation, H_2 infrastructure)

- Compare emission trading schemes

- Examine effects of energy system constraints (natural gas infrastructure, electric grid)

- Analyze benefits of region-specific policy levers (renewable portfolio standards, systems benefits charges, green power purchases)

Emissions Apportionment

- EGAS and MARKAL take economic drivers and provide emissions growth factors

- Need to capture regional variation for point, area, and mobile sources (air quality models use a 20x20 km grid)

- Potential approaches:
  - Use surrogate data (e.g., county-level population growth), subdivided into categories with specific allocation rules (statistical)
  - Integrate land-use model projections

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